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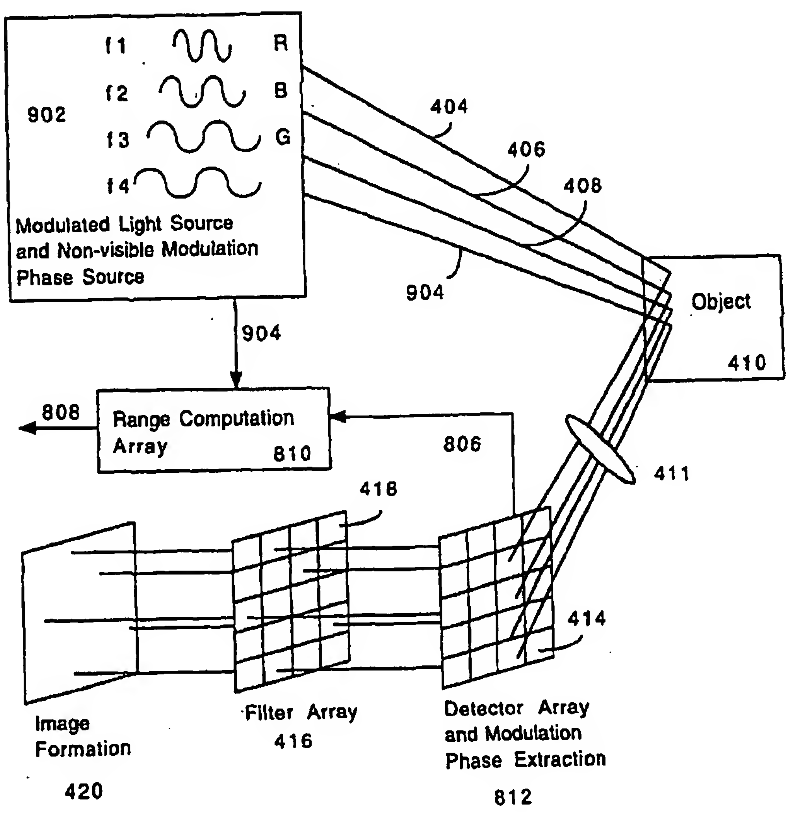
(54) Title: COLOR IMAGE PICKUP DEVICE WITH ACTIVE RANGING



(57) Abstract: Apparatus for increasing color resolution and quality in digital imaging systems temporally modulates red, green and blue light., detects all three colors at each pixel, and band pass filters the detected light to extract values for red, green and blue at each pixel. A detector which preserves the modulation, such as a complementary metal oxide semiconductor detector is used. Alternatively, if an integrating detector array such as a charge coupled device (CCD) is used, the three illumination sources are switched on and off sequentially, and the detector array switches to different integrating circuits for each color. Measurement of the range provides full color, three-dimensional, image data.

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COLOR IMAGE PICKUP DEVICE WITH ACTIVE RANGING

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to methods and apparatus for eliminating the need for color interpolation in single-array digital imaging systems by detecting modulated red, green and blue light at each pixel, and band pass filtering the detected light to extract signals representing red, green and blue.

DESCRIPTION OF THE PRIOR ART

In digital cameras, there are three generally accepted methods for acquiring color images using a light detector array. The first method is to put a color filter array (CFA) over the detector array, such that certain pixels detect certain colors. For example, some of the pixels would detect red light, some of the pixels would detect green light, and some of the pixels would detect blue light. The result of using such a color filter is that each pixel in the array sees only one color, so that to obtain a full color image, interpolation must be used to estimate the other two colors at each pixel location. Figures 1A and 1B (prior art) show how this method is used. The image obtained by the detector array through the color filter array has an arrangement of red pixels, blue pixels, and green pixels, for example in the Bayer

CFA pattern, as shown in Figure 1A. The intensity at each pixel indicates how much of the selected color of light was detected. In Figure 1B all of the pixels have all three colors of light, because the green light is interpolated between pixel G1 and pixel G4 to determine the intensity of green light in the upper left hand pixel , and so on. Thus, each three color pixel is only really accurate with respect to one of the three colors. In addition, each color array is sparsely filled. This decreases the sample rate at each color and causes increased aliasing in the image.

The second method is more expensive, and more accurate with respect to color. Three separate detector arrays are used, one for each color. Thus three images, one for each color, are formed. Then the three images are overlapped to give a composite full color image. The grey scale resolution is no better than the first method, but the accuracy of the colors is greater. Figure 2 (prior art) indicates how the three images are overlapped to generate an accurate three-color image. In addition, each array has a 100% fill factor (ratio of pixel size to pixel spacing), meaning there is little or no dead space between pixels. Consequently, aliasing is minimized.

The third method is to use a color filter wheel so that only one color illuminates the object at a time. This has the disadvantage that the field rate must be tripled to give the same frame rate. In addition, if the object moves during the exposure, the image acquires color artifacts. For example, a black/white edge appears as a color edge.

A need remains in the art for methods and apparatus for

increasing resolution and color accuracy in digital imaging systems without the need for employing multiple detector arrays, by temporally modulating red, green and blue light, detecting all three colors at each pixel, and band pass filtering the detected light to extract signals related to red, green and blue at each pixel.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide methods and apparatus for increasing resolution and color accuracy in digital imaging systems without the need for employing multiple detector arrays, by temporally modulating red, green and blue light, detecting all three colors at each pixel, and band pass filtering the detected light to extract values for red, green and blue at each pixel.

This is accomplished by sinusoidally modulating red, green and blue light sources at different frequencies. The modulation can be performed, for example, by modulating the current of the light source. The detector array detects all three colors of light at each pixel. A detector which preserves the modulation, such as a complementary metal oxide semiconductor detector is used. Three band pass filters, centered at the three modulating frequencies, are used to extract the signal associated with each color.

Alternatively, if an integrating detector array such as a charge coupled device (CCD) is used, the three illumination sources can be switched on and off sequentially, and the output read out for each color, at different times. The switching must be at three times the frame rate.

The present invention is useful in devices where artificial illumination is used, such as microscopes, endoscopes, color scanners, and manufacturing inspection cameras.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 (prior art) shows an image obtained by a detector array through the color filter array.

Figure 2 (prior art) shows the reconstructed three-color image from interpolating the pixels of the image of Figure 1A.

Figure 3 (prior art) indicates how the three one-color images are overlapped to reconstruct a three-color image.

Figure 4 is a block diagram showing three-color imaging at each pixel according to a first embodiment of the present invention wherein the colors of light is modulated.

Figure 5 is a flow diagram showing the process of three-color imaging at each pixel according to the embodiment of Figure 4.

Figure 6 is a block diagram showing three-color imaging at each pixel according to a second embodiment of the present invention wherein the colors of light are sequentially switched during one frame.

Figure 7 is a flow diagram showing the process of three-color imaging at each pixel according to the embodiment of Figure 6.

Figure 8 is a block diagram showing the embodiment of Figure 4, further including a first embodiment of ranging apparatus.

Figure 9 is a block diagram showing the embodiment of Figure 4, further including a second embodiment of ranging apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 4 is a block diagram showing three-color imaging at each pixel according to a first embodiment of the present invention wherein each color of light is modulated at a different frequency. Modulated light source 402 modulates red, blue and green light at three different frequencies. The modulated light 404, 406, 408 is reflected off object 410, imaged by lens 411, and detected by detector array 412. Detector array 412 detects all three colors of light at each pixel 414. A detector which preserves the modulation, such as a complementary metal oxide semiconductor detector is used. A band pass filter array 416 is used to extract the signal associated with each color at each pixel. Each filter element 418 comprises three band pass filters tuned to the three frequencies used to modulate the three colors of light. The signal passed by each filter element then represents the amount of light of a particular color seen by that pixel. CMOS detectors have the advantage (in addition to preserving the modulation) that the filter circuits could be built on the same semiconductor chip as the detectors. Image forming element 420 combines values for each color at each pixel and forms a three-color image of the object.

Figure 5 is a flow diagram showing the process of three-color imaging at each pixel according to the embodiment of Figure 4. In step 502, the different colors of light are modulated by different frequencies (in general three colors of light, red, green, and blue, are

used). The modulated light is reflected off of the object to be imaged in step 504. The reflected light is is imaged by lens 411 in step 505 and is detected at each pixel of the detector array 412 in step 506. In step 508, the signal from each pixel is passed through band pass filters 416 tuned to the modulating frequencies in order to extract the signal related to each color of light. The image is formed with values for all of the colors at each pixel in step 510.

Figure 6 is a block diagram showing three-color imaging at each pixel according to a second embodiment of the present invention, wherein each color of light is switched sequentially. Switching light source 602 switches between providing red, blue and green light sequentially. The light is reflected off object 610, imaged by lens 611, and detected by detector array 612. Detector array 612 is an integrating type array, so in order to preserve the information as to which color was detected as a particular time, three integrators or storage elements 615 are selected as the light source switches between colors. Image forming element 620 forms an image of the object, which has values for each color at each pixel from the three integrator arrays.

Figure 7 is a flow diagram showing the process of three-color imaging at each pixel according to the embodiment of Figure 6. In step 702, the different colors of light are switched during one frame. The light is reflected off of the object to be imaged in step 704, and is imaged onto the detector array in step 705. The reflected light is detected at each pixel of the detector array in step 706. In step 708,

the signals from the detector array are switched to the correct integrator array for the color of light provided. The signals are integrated in steps 710. The image is formed with values for all of the colors at each pixel in step 712.

Figure 8 shows a modification to the embodiment of Figure 4 which allows the system to also detect object range, using the modulation phase of at least one color of light. This feature is useful in endoscopes, manufacturing inspection, and the like. Modulated light source 802 now also provides the modulation phase of at least one of the three modulated colors as signal 804. Detector 812 also extracts the modulation phase of the same color(s) detected in each pixel and provides it as signal 806. Range computation array 810 detects the offset in modulation phase between light source 802 and after reflection off object 410, and computes the range to each imaged segment of object 410. While detecting offset in the modulation phase of only one color is necessary, detecting offset in modulation phase of more that one color may be useful for double checking the range or in resolving range ambiguities. If the phase has been offset by more than one wavelength of the modulation, there is an $n2\pi$ phase ambiguity. This ambiguity can be resolved by making measurements of the phase at different modulation wavelengths, as long as the modulation wavelengths are not integral multiples of each other.

Figure 9 shows the measurement of range by modulating a nonvisible portion of the spectrum (e.g. infrared) with a modulation wavelength to form ranging signal 904. Measurement of the phase

offset of signal 904 is then accomplished as described with respect to Figure 8. Measurement of offset in one of the colors (or another modulated infrared signal) could be used to remove range ambiguities.

Those skilled in the art will appreciate that many other configurations fall within the spirit and scope of the present invention.

What is claimed is:

CLAIMS

1. Apparatus for improved color imaging comprising:

means for sinusoidally modulating at least two different colors of light;

means for reflecting the modulated light off of an object to be imaged;

means for detecting the modulated reflected light at a plurality of pixels and generating a signal related to the detected light at each pixel, the detecting means including means for preserving the modulation;

means for filtering the signal at each pixel, in order to separate out the values of the signal related to each light color at each pixel according to its modulation; and

means for forming an image, the image forming means combining the values of the signal related to each light color at each pixel.

2. The apparatus of claim 1, wherein the means for detecting comprises a CMOS detector array.

3. The apparatus of claim 1, wherein three colors of light are modulated.

4. The apparatus of claim 1, further including means for computing

range to at least one portion of the object by comparing modulation phase of at least one color of light at the modulating means with modulation phase of the at least one color of light at a pixel of the detector array corresponding the the object portion after reflection off the object.

5. The apparatus of claim 1, further including means for computing range to the object comprising:

means for sinusiodally modulating a nonvisible portion of the light spectrum to generate a range signal;

means for transmitting the range signal along the same path as the modulated light; and

means for comparing modulation phase of the range signal at the modulating means with modulation phase of the range signal at pixels of the detector array after reflection off the object.

6. Apparatus for improved color imaging comprising:

means for switching periodically between at least two different colors of light transmitted;

means for reflecting the light off of an object to be imaged;

means for detecting the reflected light at a plurality of pixels and generating a signal related to the detected light at each pixel;

means for sequentially integrating the signal at each pixel, according to the period of each switched color, and generating a signal related to each light color at each pixel; and

means for forming an image, the image forming means combining the values of the signal related to each light color at each pixel.

7. The apparatus of claim 6, wherein the means for detecting comprises a CCD array.

8. The apparatus of claim 6, wherein three colors of light are modulated.

R1	G1	R2	G2	R3	G3
G4	B1	G5	B2	G6	B3
R4	G7	R5	G8	R6	G9
G10	B4	G11	B5	G12	B6
R7	G13	R8	G14	R9	G15
G16	B7	G17	B8	G18	B9

Figure 1 (Prior Art)

R1245 B1 G1457	R25 B12 G5	R2356 B2 G56

Figure 2 (Prior Art)

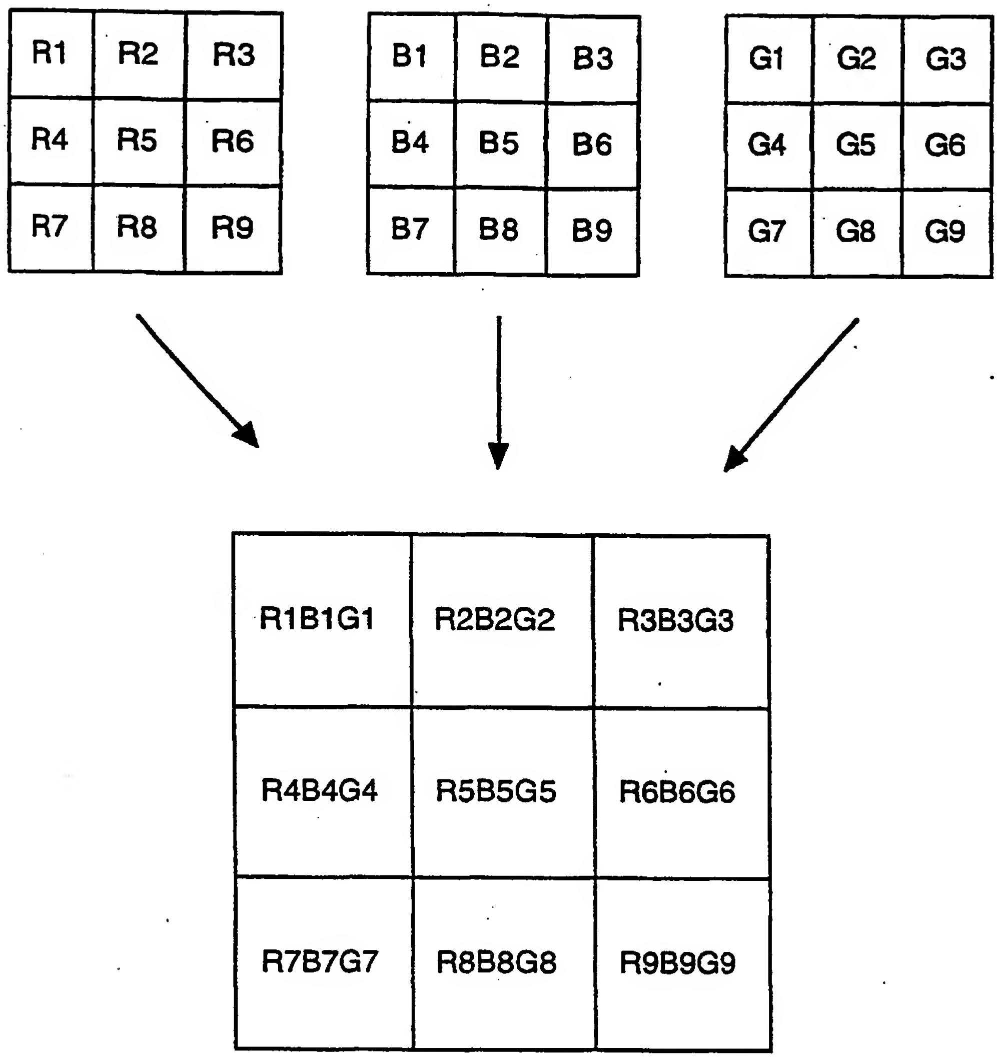

Figure 3 (Prior Art)

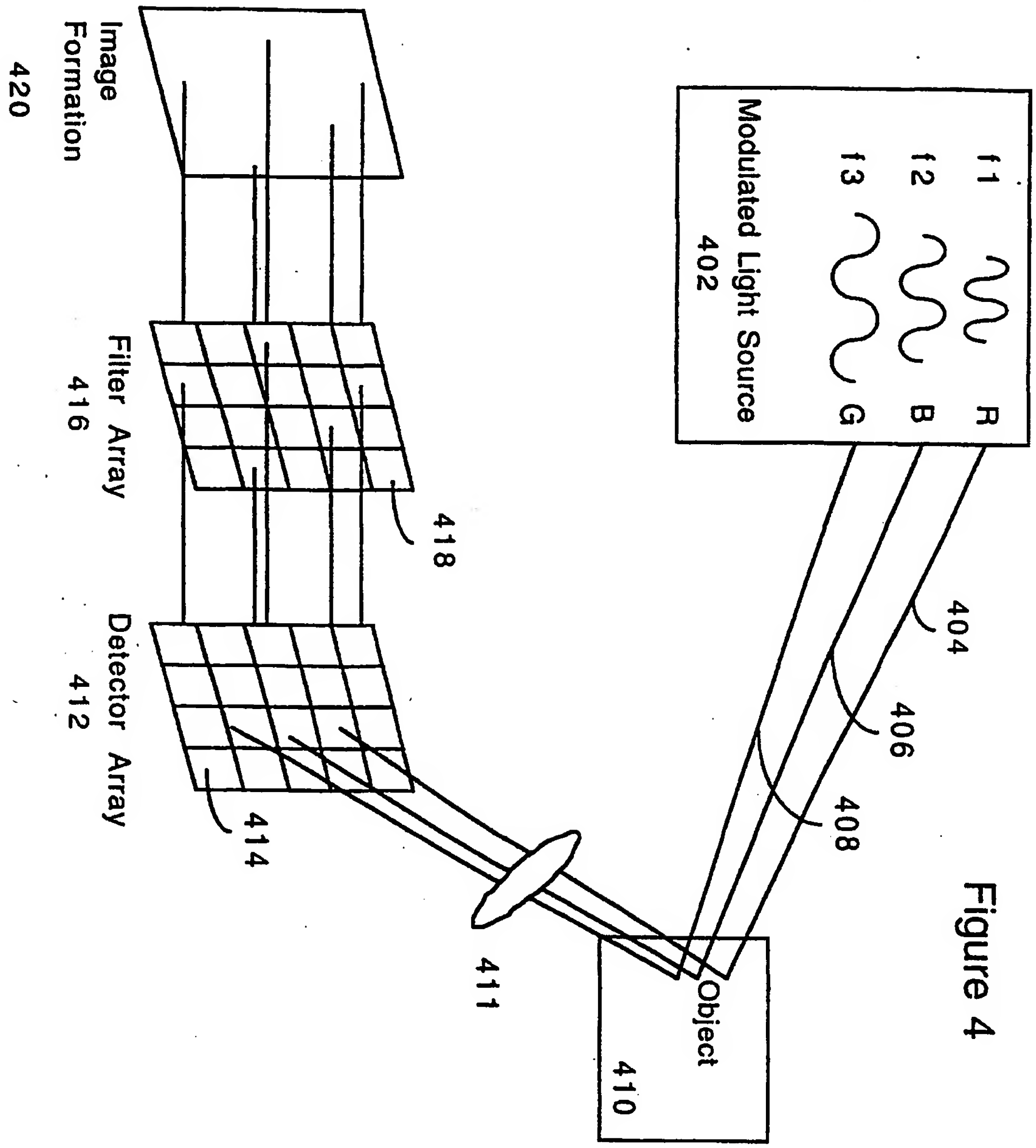
f1
f2
f3
R
B
G
Modulated Light Source
402
404
406
408
Object
410
411
Detector Array
412
414
Filter Array
416
418
Image Formation
420

Figure 4

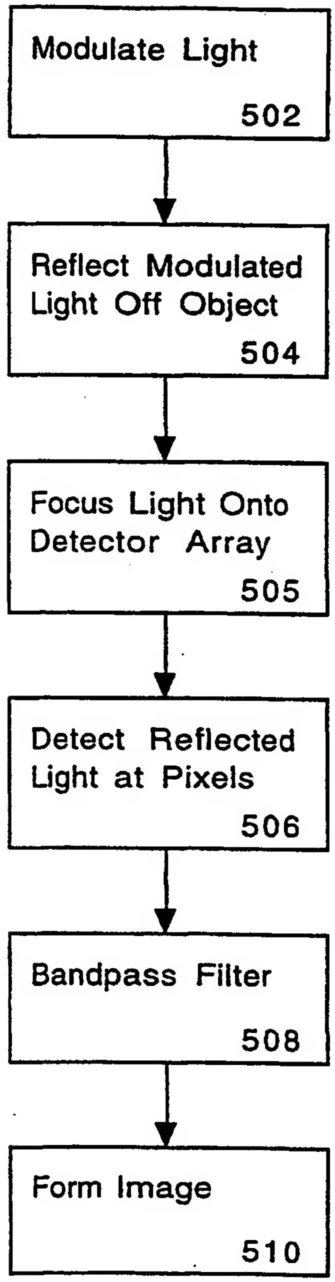
Modulate Light
502
Reflect Modulated Light Off Object
504
Focus Light Onto Detector Array
505
Detect Reflected Light at Pixels
506
Bandpass Filter
508
Form Image
510

Figure 5

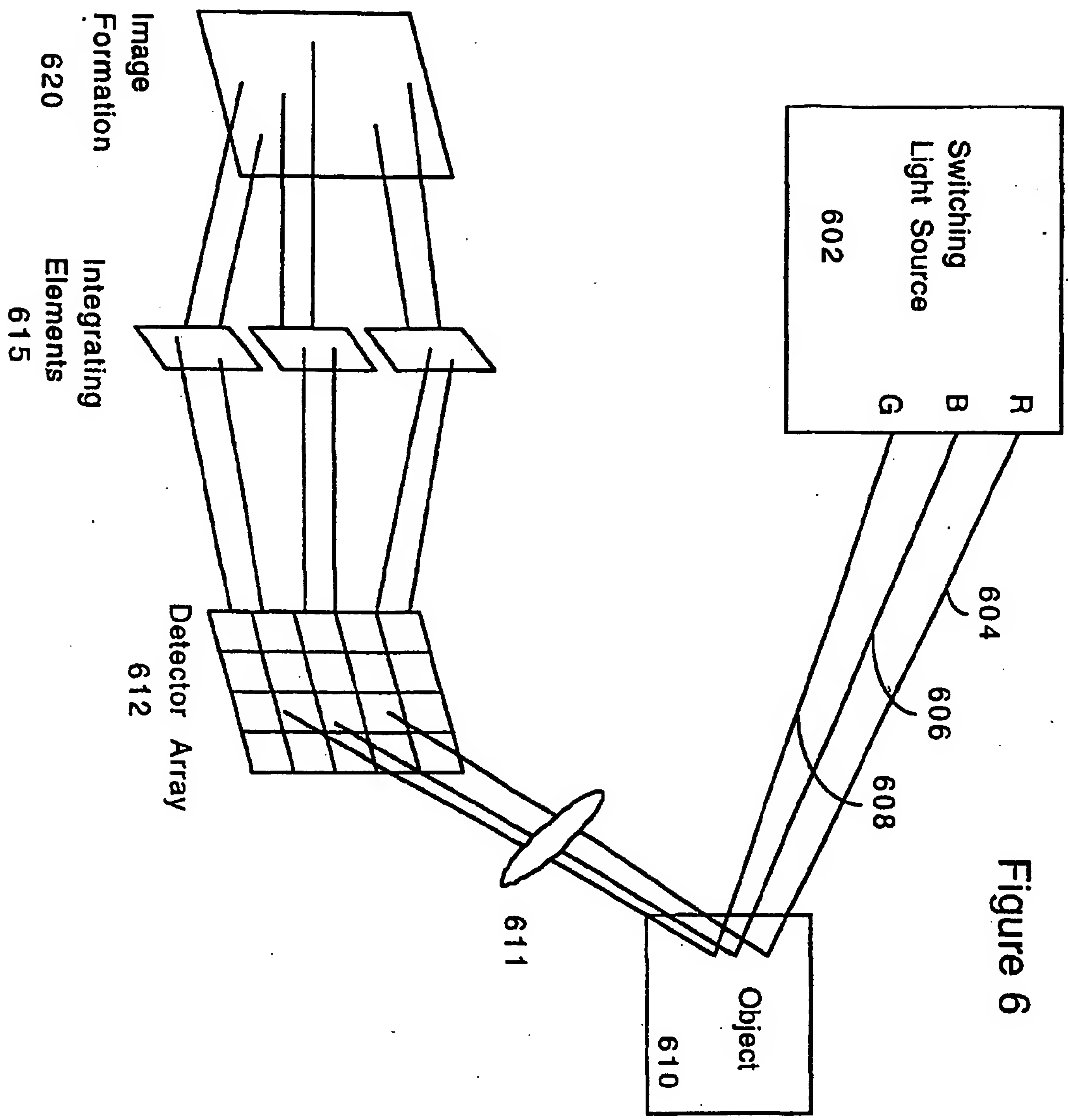
Switching
Light Source
602
R
B
G
604
606
608
Object
610
611
Detector Array
612
Integrating
Elements
615
Image
Formation
620

Figure 6

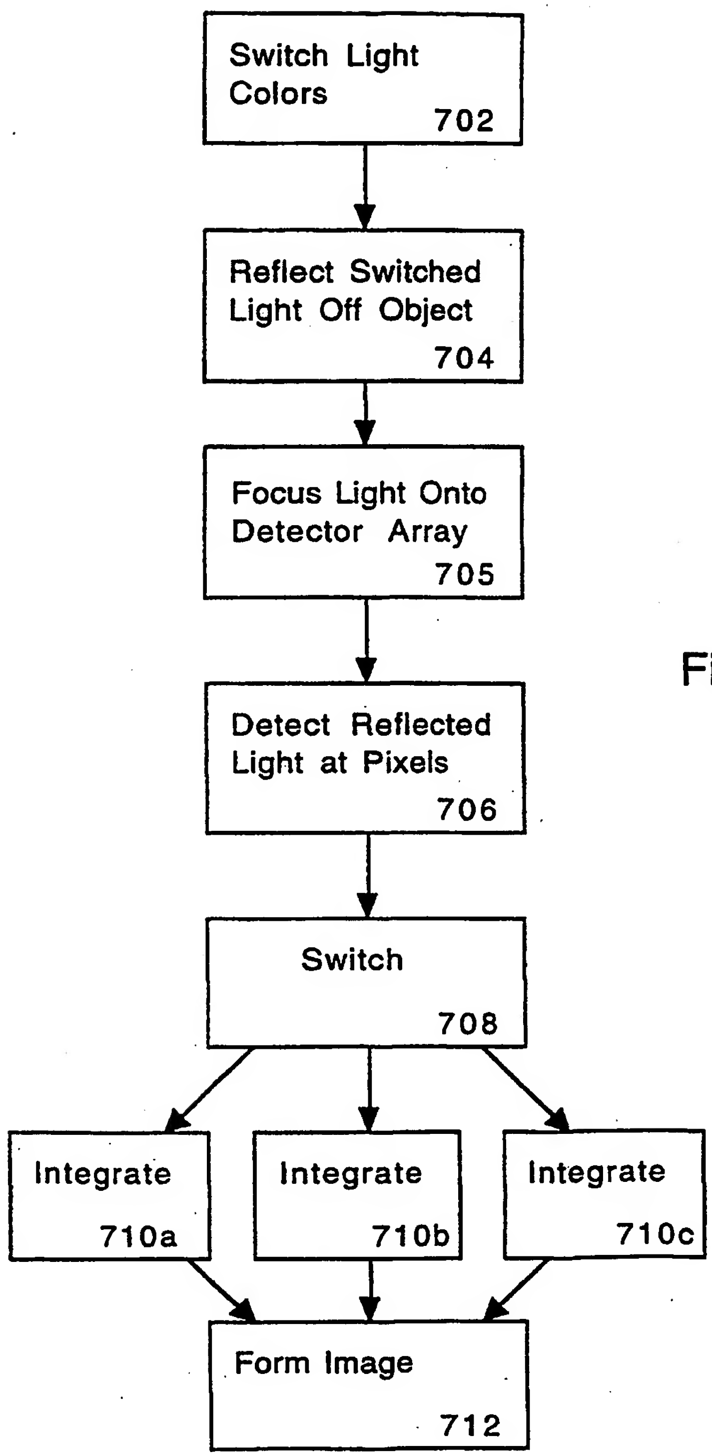
Switch Light Colors 702
Reflect Switched Light Off Object 704
Focus Light Onto Detector Array 705
Detect Reflected Light at Pixels 706
Switch 708
Integrate 710a
Integrate 710b
Integrate 710c
Form Image 712

Figure 7

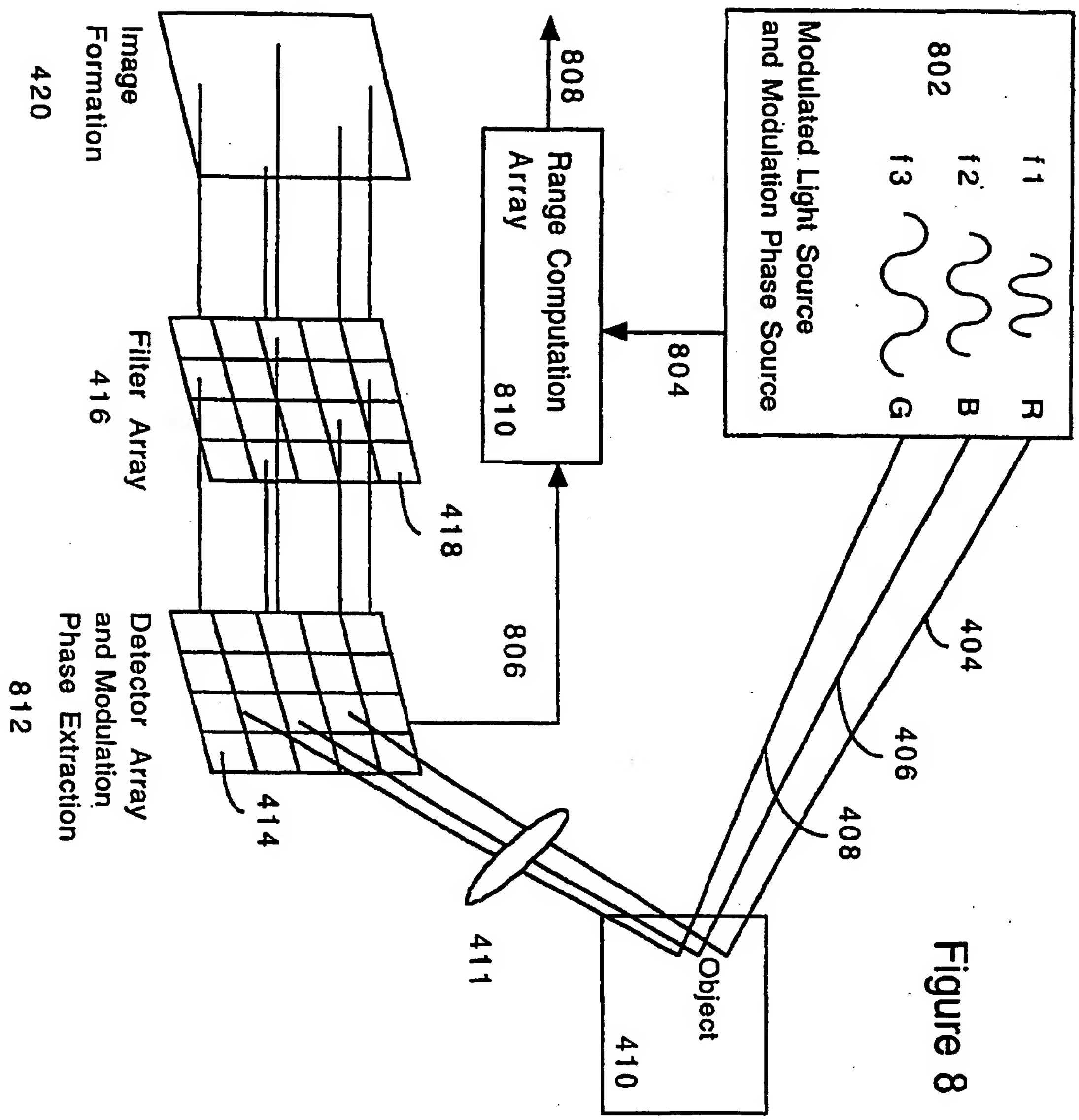
Modulated Light Source
and Modulation Phase Source
802
f1
f2
f3
R
B
G
804
808
Range Computation
Array
810
806
404
406
408
Object
410
411
Image
Formation
420
Filter Array
416
418
Detector Array
and Modulation
Phase Extraction
812
414

Figure 8

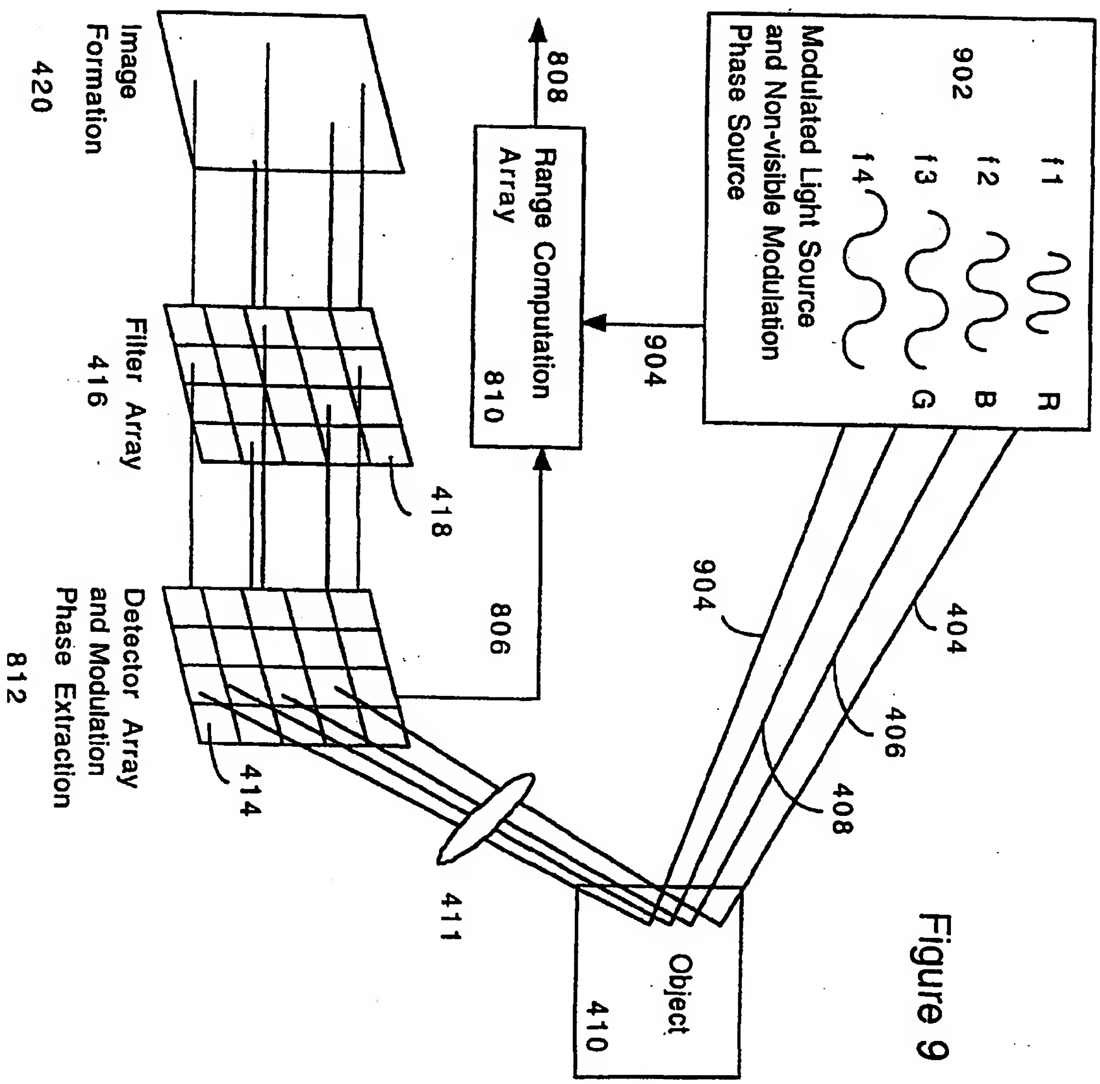
Modulated Light Source
and Non-visible Modulation
Phase Source
902
f1
f2
f3
f4
R
B
G
904
Range Computation
Array
810
808
806
404
406
408
904
Object
410
411
Detector Array
and Modulation
Phase Extraction
812
414
Filter Array
416
418
Image
Formation
420

Figure 9

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/24580

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04N9/04 G01B11/25

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04N G01B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC, COMPENDEX

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WUST C ET AL: "Surface profile measurement using color fringe projection" MACHINE VISION AND APPLICATIONS, SPRINGER VERLAG, DE, vol. 4, no. 3, 1991, pages 193-203, XP002114480 ISSN: 0932-8092	1-4,6-8
Y	Abstract Chapt. 1: Introduction Chapt. 2: Description of color fringe projection system ---	5
Y	EP 0 981 245 A (CANON KK) 23 February 2000 (2000-02-23) page 2, column 2, line 33 - line 52 --- -/--	5

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 January 2002	04/02/2002

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx. 31 651 epo nl, Fax: (+31–70) 340–3016	De Paepe, W

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/24580

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	KAWAKITA M ET AL: "AXI-VISION CAMERA: A THREE-DIMENSION CAMERA" PROCEEDINGS OF THE SPIE, SPIE, BELLINGHAM, VA, US, vol. 3958, 2000, pages 61-70, XP000987367 the whole document ---	1-8
A	US 4 349 277 A (MUNDY JOSEPH L ET AL) 14 September 1982 (1982-09-14) the whole document -----	1-8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 01/24580

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
EP 0981245	A	23-02-2000	JP	2000156823	A	06-06-2000
			EP	0981245	A2	23-02-2000
US 4349277	A	14-09-1982	CA	1164094	A1	20-03-1984
			DE	3122712	A1	18-03-1982
			FR	2484633	A1	18-12-1981
			GB	2078944	A ,B	13-01-1982
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			JP	3030802	B	01-05-1991
			JP	57024810	A	09-02-1982
			NL	8102813	A	04-01-1982